Journal of Consciousness Studies
www.imprint-academic.com/jcs

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The 'Shared Manifold' Hypothesis

From Mirror Neurons To Empathy

I: Introduction

We are social animals. We share this feature with many other species. A complexity and sophistication that we do not observe among ants, bees or wolves, however, characteristically define the social life of primates. This complexity and sophistication is epitomized at its highest level by the social rules our conduct in everyday life is supposed to comply with. Living in a complex society requires individuals to develop cognitive skills enabling them to cope with other individuals' actions, by recognizing them, understanding them, and reacting appropriately to them. No one doubts that the extant primate ancestors of ours, monkeys and apes, who indeed also live in complex, hierarchically organized societies, are perfectly able to cope with *their own* social rules. Nevertheless, it is commonly argued that to achieve that goal non-human primates simply rely on behaviour observation. Animals do not represent rules in their minds, and they do not engage in any *inference*-based reasoning. Accordingly, what non-human primates are lacking would sharply define what is considered to be uniquely human: *truly* cognitive states, such as intentions, desires and beliefs.

In our daily life we are constantly exposed to the actions of the individuals inhabiting our social world. We are not only able to describe these actions, to understand their content, and predict their consequences, but we can also attribute *intentions* to the agents of the same actions. We can immediately tell whether a given observed act or behaviour is the result of a purposeful attitude or rather the unpredicted consequence of some accidental event, totally unrelated to the agent's will. In other words, we are able to understand the behaviour of others in terms of their mental states. I will designate this ability as *mind-reading*. How do we 'read' intentions in the mind of other individuals? A common view maintains that all normal humans develop the capacity to *represent* mental states in others by means of a conceptual system, commonly designated as 'Theory of Mind' (TOM, see Premack and Woodruff, 1978).

My initial scope will be limited: starting from a neurobiological standpoint, I will analyse how actions[1] are possibly *represented* and *understood*. The main aim of my

[1] In this paper I will mostly focus on action understanding. This of course doesn't exhaust the issue of social cognition. The reader can refer to the excellent review by Adolphs (1999) for an appreciation of the role of emotions in social cognition. See Damasio (1994; 1999); Ellis and Newton (2000); Jarvilehto (forthcoming); Panksepp (2000) for a discussion of the relation between emotions and consciousness.

Journal of Consciousness Studies, **8**, No. 5–7, 2001, pp. 33–50

arguments will be to show that, far from being *exclusively* dependent upon mentalistic/linguistic abilities, the capacity for understanding others as intentional agents is deeply grounded in the *relational* nature of action. Action is relational, and the relation holds both between the agent and the object target of the action (see Gallese, 2000b), as between the agent of the action and his/her observer (see below). *Agency* constitutes a key issue for the understanding of intersubjectivity and for explaining how individuals can interpret their social world. This account of intersubjectivity, founded on the empirical findings of neuroscientific investigation, will be discussed and put in relation with a classical tenet of phenomenology: empathy.[2] I will provide an 'enlarged' account of empathy that will be defined by means of a new conceptual tool: the *shared manifold* of intersubjectivity.

II: How Do We Perceive Actions?

To 'navigate' in our social environment we rely basically on vision. It is through vision that we are able to recognize different individuals, to locate them in space, and to record their behaviour. Vision, among the different sensory modalities, is indeed by far the most extensively studied one both by psychology and by neuroscience. About fifty years of neuroscientific investigation have clarified many aspects of vision, from the transduction processes carried out at the interface between light stimuli and receptors in the retina, to the different stages along which visual images are processed and analysed by the brain. In this section I will confine my review to data obtained from monkeys. The problem of how the human brain processes actions will be addressed later on in the paper.

The most widely accepted model of how the brain analyses visual information maintains that visual processing is carried out in a piecemeal fashion, with specialized cortical regions 'dedicated' to the analysis of shape, colour and motion (for a comprehensive neuroscientific account of vision, see Zeki, 1993).

Motion analysis is crucial to discriminate and recognize observed actions performed by other individuals. Area MT, or V5 (Zeki and Shipp, 1988), which in the monkey is located in the caudal part of the ventral bank of the Superior Temporal Sulcus (STS), is one of the most studied among the so-called extrastriate visual areas. Several electrophysiological studies have shown that area MT is specialized for the analysis of visual motion (Dubner and Zeki, 1971; Zeki, 1974; Van Essen *et al.,* 1981; Maunsell and Van Essen, 1983; Desimone and Ungerleider, 1986). Interestingly enough, however, comparatively little effort has been devoted to the investigation of where and how *biological motion* is analysed and processed in the brain.

The seminal studies carried out by David Perrett and co-workers since the mid-eighties (Perrett *et al.,* 1989; 1990; Oram and Perrett, 1994), have filled this gap by clarifying that in a cortical sector buried within the anterior part of the Superior Temporal Sulcus (STSa) of the monkey there are neurons, not tested for the presence of motor properties, selectively activated by the observation of various types of body movements such as walking, turning the head, stretching the arm, bending the torso, etc. (for review, see Carey *et al.*, 1997; Jellema and Perrett, 2001). Particularly interesting

[2] The theoretical approach I'll be advocating here is in part related to Simulation Theory (see Gordon, 1986; Harris, 1989; Goldman, 1989; 1992; 1993a,b; 2000).

are cells responsive to *goal-related behaviours*: these neurons do not respond to static presentations of hands or objects, but require, in order to be triggered, the observation of a meaningful, goal-related hand–object interaction (Perrett *et al.*, 1990). Incidentally, it must be noted that no attempt has been made by these authors to test the responsiveness of these neurons during active movements of the monkey. Comparable hand actions without target object or hand movements without physical contact with the object in view do not evoke any response. The responses of these neurons generalize across different viewing conditions including distance, speed and orientation. The responses of some of these neurons have been shown not to be sensitive to form, so that even light dot displays moving with a biologically plausible kinematics are as good as true limbs and hands in evoking the neurons' discharge (Oram and Perrett, 1994; Jellema and Perrett, 2001).[3] Neurons responding to complex biological visual stimuli such as walking or climbing were reported also in the amygdala (Brothers *et al.*, 1990).

Altogether these results provide strong evidence supporting the notion that distinct specific sectors of the visual system are selectively involved in the representation of behaviours of others. *Visual representation*, however, is not *understanding*. A visual representation of a given stimulus doesn't necessarily convey all the information required to assign a meaning to it, and therefore to understand such a stimulus. What a purely visual representation of a behaviour doesn't allow for is to code/represent it as an *intended, mind-driven* behaviour.

In the next section I will briefly present some empirical results that may help in elucidating the neural mechanisms at the basis of a more comprehensive account of action understanding.

III: Mirror Neurons and Action Representation

In a series of single neuron recording experiments we discovered (diPellegrino *et al.*, 1992; Gallese *et al.*, 1996a; Rizzolatti *et al.*, 1996a; Gallese, 1999; 2000a; see also Rizzolatti *et al.*, 2000) in a sector of the monkey ventral premotor cortex, area F5 (Matelli *et al.*, 1985; Rizzolatti *et al.*, 1998), that a particular set of neurons, activated during the execution of purposeful, goal-related hand actions, such as grasping, holding or manipulating objects, discharge also when the monkey observes similar hand actions performed by another individual. We designated these neurons as 'mirror neurons' (Gallese *et al.*, 1996a; Rizzolatti *et al.*, 1996a). Mirror neurons require, in order to be activated by visual stimuli, an interaction between the action's agent (human being or a monkey) and its object. Control experiments showed that neither the sight of the agent alone nor of the object alone were effective in evoking the neuron's response. Similarly, much less effective were mimicking the action without a target object or performing the action by using tools (Gallese *et al.*, 1996a).

[3] These results suggest that the triggering feature for neurons responsive to the observation of goal-related behaviours is the embedded motor schema rather than a purely visual representation of the observed behaviour. The results of Cutting and Kozlowski (1977) seem to support this view. When human subjects watch moving light-dot displays they are not only capable to recognize a walking person, but also to discriminate whether it is them or someone else that they are watching. Since in normal conditions we never look at ourselves when walking, this recognition process can be much better accounted for by a simulation mechanism in which the observed moving stimuli activate the observer's motor schema for walking, than solely by means of a purely visual process. See also Churchland *et al.* (1994) for a critique of *pure* vision.

Frequently, a strict congruence was observed between the observed action effective in triggering the neuron and the effective executed action. In one third of the recorded neurons the effective observed and executed actions corresponded both in terms of the general action (e.g. grasping) and in terms of the way in which that action was executed (e.g. precision grip). In the other two thirds only a general congruence was found (e.g. any kind of observed and executed grasping elicited the neuron's response). This latter class of mirror neurons is particularly interesting, because they appear to generalize across different ways of achieving the same goal, thus perhaps enabling a more abstract type of action coding.

The lack of responsivity of mirror neurons during the observation of actions performed with tools is reminiscent of a study of Meltzoff (1995) where he studied and described the capacity of 18-month-old children to re-enact observed goal-directed actions displayed by adult demonstrators. In one case the adult demonstrator pulled the end of a toy dumbbell designed to be pulled apart, but actually failed in pulling it apart. Toddlers who observed this intended — but failed — action were nevertheless able to re-enact it successfully, even if they had never been exposed before to a successful version of the same action. This capacity, however, disappeared when they observed the same failed attempt to pull the dumbbell apart demonstrated by a mechanical device.

These results tell us that in order to understand the intended goal of an observed action, and to eventually re-enact it, a *link* must be established between the observed agent and the observer. My proposal is that this link is constituted by the *embodiment* of the intended goal, shared by the agent and the observer. We can speculate on the mechanisms enabling the embodiment of the intended goal to be shared. My suggestion is that the embodiment of the action goal, shared by agent and observer, depends on the motor schema of the action, and not only on a purely visual description of its agent.[4] When the motor schema of the agent is different from that of the observer — as in the case of the mechanical demonstrator, or for mirror neurons, in the case of grasping achieved by using a tool — the observed action cannot be matched on the observer's motor repertoire, and therefore the intended goal cannot be detected and/or attributed to the mechanical agent.

A striking resemblance can be found between mirror neurons and the STSa neurons responsive to biological meaningful visual stimuli, described in the macaque brain by Perrett and coworkers (see above). Mirror neurons differ from these complex visual neurons in that the former discharge also during active movements of the observer. They constitute, therefore, a specific neural system matching action observation and execution. The observed action produces in the observer's premotor cortex an activation pattern resembling that occurring when the observer actively executes the same action.

A problematic issue since the discovery of F5 mirror neurons has been the source of their visual input. At first sight the STSa neurons described by Perrett and coworkers (for a recent review, see Jellema and Perrett, 2001) could provide a particularly

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[4] It can be objected that a tool or a mechanical device looks *stranger* to a primate observer because of its shape. This is certainly true. However, the action-observation neurons described by Perrett (Oram and Perrett, 1994) that respond to moving light dot-displays seem to suggest that action schemas constitute a major cue for the detection of goal-relatedness (see also note 3).

well suited source of visual input to F5 mirror neurons. However, area F5 does not receive direct projections from the STS region. One of the major inputs to area F5 comes from the inferior parietal lobule (Petrides and Pandya, 1984; Matelli *et al.*, 1986; Cavada and Godman-Rakic, 1989), and in particular from area 7b or PF (see Rizzolatti *et al.*, 1998). The inferior parietal lobule, in turn, is reciprocally connected with the STS region (Seltzer and Pandya, 1984; Cavada and Goldman-Rakic, 1989).

Thus, visual information about actions could be fed to area F5 from the STSa region through an intermediate step in the posterior parietal cortex. In order to verify whether 'mirror properties' could be detected in the posterior parietal cortex, my colleagues and I decided to study the functional properties of area 7b by means of single neuron recording experiments. Neuron properties were examined during active movements of the monkey and in response to somatosensory and visual stimuli, including goal-related hand movements. About one third of the recorded neurons responded both during action execution and action observation (Fogassi *et al.* 1998; Gallese *et al.*, 2001a). These data, although preliminary, indicate that an action observation/execution matching system exists also in the posterior parietal cortex, possibly constituting part of a cortical network for action recognition (see Gallese *et al.*, 2001a).

What may be the function of a neural system matching action observation and execution? Before discussing this issue it is important to stress that the presence of such a system has been demonstrated also in humans. Fadiga *et al.* (1995) tested the excitability of the motor cortex of normal human subjects with the technique of transcranic magnetic stimulation under three different conditions: observation of an experimenter grasping objects; observation of objects; detection of the dimming of a small spot of light. The results showed that during grasping observation the motor evoked potentials recorded from the hand muscles markedly increased with respect to other conditions, including the attention demanding dimming-detection task. Furthermore, the increase of excitability was present only in those muscles that were used by the subjects when actively performing the observed movements.

Similar results were obtained also by Cochin *et al.* (1998), who recorded EEG from subjects who observed video movies in which human movements were displayed. As control, objects in movement, and still objects were also presented. The results showed that the observation of human movements, but not that of objects, desynchronizes the EEG pattern of the precentral motor cortex. The same results have been replicated (Hari *et al.*, 1998) by using a different technique, magnetoencephalography (MEG).

All these studies suggested that humans have a 'mirror matching system' similar to that originally discovered in monkeys. Whenever we are looking at someone performing an action, beside the activation of various visual areas, there is a concurrent activation of the motor circuits that are recruited when we ourselves perform that action. Although we do not overtly reproduce the observed action, nevertheless our motor system becomes active *as if*[5] we were executing that very same action that we are observing. To spell it out in different words, action observation implies *action simulation*.[6]

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[5] *As if* mechanisms have been pinpointed by Damasio (1999) as being part of the system enabling the experience of emotional feelings (see also below).

[6] For a discussion of simulation in relation to representation, see Gallese (2000b).

With the use of brain imaging techniques the localization of cortical areas active during action observation was made possible. Initial studies showed that during the observation of different type of hand grips performed on a variety of objects there is an activation of left STS region, of the inferior parietal lobule and of Broca's area (see Rizzolatti *et al.*, 1996b; Grafton *et al.*, 1996; Decety *et al.*, 1997; for review, see Decety and Grézes, 1999; Allison *et al.*, 2000). This circuit roughly corresponds to that of mirror neurons in the monkey.[7] However, in all these brain imaging experiments the actions that human subjects were required to observe were limited only to hand actions.

More recently, in a fMRI study, subjects were shown object-directed actions made with the mouth (e.g. biting an apple), the hand (e.g. grasping a cup) and the foot (e.g. kicking a ball). The results showed that observation of object-related actions determines, among other activations, a somatotopically-organized activation of the premotor cortex. During mouth actions observation there is a bilateral activation of the ventral premotor cortex (Brodmann's area 6) plus an activation of Broca's area. During hand actions observation a more dorsal part of ventral area 6 plus Broca's area are recruited. Finally, the observation of foot actions elicits an activation of dorsal area 6 (Buccino *et al.*, 2001).

It appears therefore that when we observe goal-related behaviours executed with different effectors, different specific sectors of our pre-motor cortex become active. These cortical sectors are those same sectors that are active when we actually perform the same actions. In other words, when we observe actions performed by other individuals our motor system 'resonates' along with that of the observed agent.

As stated above, action observation both in humans and monkeys seems to imply a concurrent action simulation. This notion is corroborated by evidence coming from neurological patients. Demented patients with 'echopraxia' (Dromard, 1905; Stengel *et al.*, 1947) show an impulsive tendency to imitate other people's movements. Imitation is performed immediately with the speed of a reflex action. Imitation concerns gestures that are commonly executed as well as those that are rare and even bizarre for the observing patient. It can be hypothesized that echopractic behaviour represents a 'release' of a covert action simulation present also in normal subjects, but normally inhibited in its expression by the cortical areas that in these patients are functionally defective. A similar case has been reported of patients that, due to lesion of the orbito-frontal cortex, display what has been defined as 'imitative behaviour' (Lhermitte *et al.*, 1986). Unlike in echopraxia, however, patients with imitation behaviour do not imitate the *movements* of the acting individual, but rather perform an *action* identical to the observed one. It is the goal rather than movement to be imitated in this pathology.[8] A much less dramatic example of 'contagious behaviour' commonly

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[7] Broca's area is considered the human homologue of the monkey's area F5 (see Matelli and Luppino, 1997; Rizzolatti *et al.*, 1998). For a discussion of mirror neurons in relation to motor theories of speech perception and the origin of language, see Fadiga and Gallese (1997); Rizzolatti and Arbib (1998); Gallese (1999).

[8] Imitation plays a major role in the cognitive development of humans. Much debated, however, is the relevance of imitative behaviour among non human primates (see Hayes, 1998; Tomasello *et al.*, 1993; Byrne and Whiten, 1988; Byrne, 1995; Byrne and Russon, 1999; Whiten, 1996; Whiten and Ham, 1992). The reader interested to know more about the possible relation between mirror neurons and imitation can refer to Jeannerod (1994; 1997); Gallese and Goldman (1998); Rizzolatti *et al.* (1999; 2001).

experienced in our daily life, in which the observation of particular actions displayed by others leads to our repetition of them, is represented by yawning and laughter.

In the next section I will try to demonstrate that it is not fortuitous that part of the motor system is involved in *representing* action, by showing that a link can be established between action control and action representation (for a discussion of representation in relation to motor control, see also Gallese, 2000b).

IV: Agency and Intersubjectivity

So far we have seen that both humans' and monkeys' motor systems are active not only during the execution of goal-related movements but also during their observation.

Why do individuals possess a 'mirror matching mechanism'? The capability of individuals to adapt to a particular social environment relies upon the possibility to select a certain type of behaviour also on the basis of the understanding of the behaviour displayed by other individuals. My proposal is that action understanding heavily relies on a neural mechanism that matches, in the same neuronal substrate, the observed behaviour with the one executed (Gallese *et al.*, 1996a; Rizzolatti *et al.*, 1996a; Gallese, 2000a). According to this hypothesis, 'understanding' is achieved by modelling a *behaviour* as an *action* with the help of a motor equivalence between what the others do and what the observer does.[9]

The neuroscientific results here briefly summarized seem to point to a crucial role played by action, in virtue of its *relational nature*, in establishing a meaningful link between agent and observer. Action execution and action observation both impinge upon the same cortical network: why is this so? How come that when we observe someone acting, our motor system starts to covertly simulate the actions of the observed agent? Why shouldn't a purely visual representation of the observed behaviour of others suffice to account for it? I will try to answer this question by providing a non conventional account of *action representation*.

The fact that the motor system is activated not only when a given action is executed, but also when it is observed, suggests that a relationship may exist between *action control* and *action representation*. As I hope it will become clearer in a while, both achievements are necessarily tied to the necessity of organisms to model themselves (see also Metzinger, 1993; 2000). Furthermore, it must be noted that social cognition also has action control as one of its main purposes, namely controlling the action of others. These statements, nevertheless, need to be qualified and substantiated by empirical data. The neurophysiological study of the functional organization of the ventral premotor cortex of the monkey provides very interesting clues that may help us to provide a new and unconventional account of how actions are represented.

Mirror neurons have been discovered in area F5, which constitutes the most rostral part of the ventral premotor cortex.[10] This area can be functionally parcelled in two sectors: one sector occupies the cortical convexity, and it is in this sector that mirror

[9] Unlike introspection, however, this process is automatic, unconscious and non predicative. This is not meant to deny that this particular type of representational content is open to introspective access. My point is that conscious introspective access is not *necessarily required* to detect intentions in the observed behaviour of others (see also Goldman, 2000, on this point).

[10] The majority of F5 neurons code goal-related hand, mouth or hand and mouth actions such as grasping, holding, and tearing objects. Part of these neurons has also visual properties (see below).

neurons are mostly clustered. The second sector is buried within the inferior limb of the arcuate sulcus, of which it constitutes the posterior bank. In this latter sector, a second class of visuomotor grasping-related neurons have been described, 'canonical neurons' (Rizzolatti *et al.*, 1988; Murata *et al.*, 1997; Rizzolatti *et al.*, 2000; Gallese, 2000a). Canonical neurons are activated during the execution of goal-related movements such as grasping, holding, and manipulating objects. Unlike mirror neurons, however, they are not activated by action observation. They discharge during object observation, typically showing congruence between the type of grip they motorically code and the size/shape of the object that visually drives them. Both sectors of F5 are reciprocally connected to the primary motor cortex, area F1 (see Matelli *et al.*, 1986; Rizzolatti *et al.*, 1998).

In a particular sector of the premotor cortex — area F5 — there are therefore two distinct classes of neurons that code goal-related hand movements, and which differ for their visual responsiveness: mirror neurons respond to action observation, while canonical neurons respond to object observation. Why are there two distinct populations of grasping-related premotor neurons? By answering this question we can start to develop a new account of *re-presentation*.

My proposal is to interpret the motor activity of mirror neurons in terms of an *efference copy* of the motor program signal. Once the features of the object to be grasped are specified, and 'translated' by canonical neurons into the most suitable motor program enabling a successful action to be produced (see Jeannerod *et al.*, 1995; Gallese *et al.*, 1996b; Rizzolatti *et al.*, 2000), a copy of this signal is fed to mirror neurons. This signal would act as a sort of 'simulator' of the programmed action. This *simulation* of the action is used to predict its consequences, thus enabling the achievement of a better control strategy.

My hypothesis can be framed within the logic of the so-called *forward models*. Forward models are so defined because they can capture the forward or causal relationship between actions, as signalled by efference copy, and outcomes. By means of forward models the outcomes of motor commands can be estimated (Wolpert *et al.*, 1995; Wolpert, 1997; Kawato, 1997; 1999).

An instantiation of the activity of forward models can be found in the domain of postural control (Cordo and Nashner, 1982). When I am going to stretch my arm to grasp a handle in front of me, the resulting postural perturbation that would follow, causing my body to bend, is cancelled by a forward signal sent to the posterior muscles of my leg, which stabilize my standing posture. The muscles of the leg indeed contract well before my arm is set into motion. The contraction of leg muscles anticipates, *predicts* the outcome of the programmed action of the arm, that is, the forecast postural perturbation, preventing it to occur. Neither overt knowledge nor conscious inference is involved in this process.

I posit that a similar functional architecture might be at work also in the far more complex domain of intersubjective relationships. The same basic functional architecture that proved itself to be so useful in one domain can be exploited also in a different one. When trying to account for the cognitive abilities of human beings we tend to forget that these abilities were not modelled and put in place as such, but they are the result of a long evolutionary process. The hypothetical scenario here briefly sketched has the advantage of being more plausible in evolutionary terms than accounts that

emphasize a sharp discontinuity between human cognition and that of all other living creatures (see below; see also Gallese *et al.*, 2001b).

Mirror neurons are active during action execution: if we interpret the *motor activation* of mirror neurons as the result of an *efference copy signal*, it is possible to speculate that this system may have originally developed to achieve a better control of action performance. The coupling of this forward model architecture with the vision of the agent's own hand, and its later generalization to the hands of others, may have allowed this system to be used also for totally different purposes, namely to represent other individuals' actions. Action representation, following my hypothesis, can be envisaged as the emergence of a new skill that developed by exploiting in totally new ways resources that had been previously selected for other purposes, namely for motor control purposes.

I must admit that this is no more than a purely speculative scenario. We don't know whether there is a developmental stage in which mirror neurons respond to the sight of the acting agent's own hand, but not yet to the sight of another observed agent. We don't even know whether mirror neurons in the monkey — or analogous neurons in humans — are already present at birth,[11] or whether they are the developmental result of the exposure of the developing individual to action observation.[12] Whatever the evolutionary history of the mirror matching system may be, at the phylogenetic as well as at the ontogenetic level, it is clear that the discovery of mirror neurons provide a strong neurobiological basis for a subpersonal account of inter-subjective representational content.

When a given action is planned, its expected motor consequences are forecast. This means that when I am going to execute a given action I can predict its consequences. Through a process of 'motor equivalence' I can use this information also to predict the consequences of actions performed by others. This *implicit*, *automatic*, and *unconscious* process of motor simulation enables the observer to use his/her own resources to penetrate the world of the other without the need for *theorizing* about it (see note 9), without the need to necessarily use *propositional attitudes*. A process of action simulation automatically establishes a direct implicit link between agent and observer. Action is the 'a priori' principle enabling social bonds to be initially established. By an implicit process of *action simulation*, when I observe other acting individuals I can immediately recognize them as goal-directed agents like me, because the very same neural substrate is activated as when I myself am bound to achieve the

[11] The capacity of newborn babies to imitate facial gestures, such as opening the mouth or protruding the tongue (Meltzoff and Moore, 1977), suggests that some form of 'mirror-like' mechanisms may be in place already at birth, at least for parts of the body that cannot be directly observed, and therefore likely require an active mirroring into the body of others to be better controlled.

[12] There is evidence that congenitally limb deficient patients develop phantom limb sensations (the so-called *aplasic phantoms*), despite the fact that they never moved these absent parts of their bodies (see Ramachandran, 1993; Melzak *et al.*, 1997; Ramachandran and Rogers-Ramachandran, 1996; Ramachandran and Hirstein, 1998). In a recently published study, Brugger *et al.* (2000) describe one of these cases. fMRI imaging of their patient during phantom limb sensations of hand movements showed no activation of primary sensorimotor areas, but of premotor and posterior parietal cortex. The authors of this study conclude that aplasic phantoms could be explained by postulating the existence of an innate but plastic schema for matching the observation with the execution of motor actions. Phantom limbs could therefore be explained as the phenomenal correlate of planning action with an absent limb.

same goal by acting. In sum, my suggestion is that through a process of 'motor equivalence' a meaningful link between agent and observer can be established.

Mirror neurons are found in cortical regions endowed with motor properties because premotor neurons are able to establish relationships between expectancies and results. Thus, action understanding can be viewed as a *subpersonally instantiated function*. It relies on neural circuits involved in action control. This pushes us to discuss the relationship between the *embodied mechanisms* at the basis of intersubjectivity that I have briefly illustrated here and the *disembodied* accounts of how the mind can represent the world of living creatures heralded by cognitivism.

V: The Social Mind, Its Theories, and Empathy

As anticipated in the Introduction, it is commonly held that all normal humans develop the capacity to *represent* mental states in others by means of a conceptual system, commonly designated as 'Theory of Mind' (TOM, see Premack and Woodruff, 1978). TOM has rapidly become a major topic in the cognitive sciences and in the philosophy of mind (see Carruthers and Smith, 1996, for an excellent survey of the issue). The concept of TOM can be addressed from many different perspectives. We can describe TOM in terms of a domain specific ability, supported by an innate, encapsulated, and specific module, whose function is segregated from the other intellectual capacities of the individual (Leslie, 1987; Baron-Cohen, 1995; Fodor, 1992; 1994). Alternatively, we can conceive TOM as the final stage of a developmental process in which different scientific theories about the world and its inhabitants are tested and eventually discarded to adopt new ones (see the 'child-as-scientist' hypothesis by Gopnik and Meltzoff, 1997). Both accounts of TOM are often referred to as Theory-Theory. Or, finally, we can conceive TOM as the result of a *simulation routine* by means of which we can *pretend* to be in the other's 'mental shoes' and use our own mind as a model for the mind of others (Gordon, 1986; Harris, 1989; Goldman, 1989; 1992; 1993a, b; 2000).

Both theory-theory approaches can be framed within classic cognitivism. The picture of the mind conveyed by classic cognitivism is that of a functional system whose processes can be described in terms of manipulations of informational symbols according to a set of formal syntactic rules (see Fodor, 1981; Pylyshyn, 1984). Thus, following the line of arguments of cognitivism, representations are symbolic in their nature, and thinking can be reduced to computation. It is therefore consequent that the understanding of other minds is conceived solely as a predicative, inferential, theory-like process.

It is out of the scope of this paper to add more to the debate on TOM (for an interdisciplinary discussion of Simulation Theory and its possible neural bases, see Gallese and Goldman, 1998, and Goldman and Gallese, 2000). The empirical data that I briefly reviewed in the first part of the paper suggest that it is possible to considerably deflate the role played by abstract *theorizing* when ascribing mental states (at least *some* mental states) to others. My thesis is that many aspects of our felt capacity to entertain social relationships with other individuals, the ease with which we 'mirror' ourselves in the behaviour of others and recognize them as similar to us, they all have a common root: empathy.

My proposal is to revise the concept of empathy by extending it so to account for all different aspects of behaviour enabling us to establish a meaningful link between

others and ourselves. This 'enlarged' account of empathy will open up the possibility to provide a more comprehensive account of intersubjective intercourses, leading to a new conceptual tool that I'll define in the next section. But let us first try to clarify the meaning of the term empathy.

Empathy is a later English translation of the German word Einfühlung, originally introduced by Theodore Lipps (1903a) into the vocabulary of the psychology of aesthetic experience, to denote the relationship between an artwork and the observer, who imaginatively projects herself into the contemplated object. Lipps (1903b) extended the concept of Einfühlung also to the domain of intersubjectivity that he characterized in terms of *inner imitation* of the perceived movements of others. When I am watching an acrobat walking on a suspended wire, Lipps (1903b) notes, *I feel myself inside of him* (Ich Fühle mich so in ihm).

Phenomenology has further developed this concept. In the posthumously published Ideen II (1989, English translation), Husserl emphasizes the role of the acting body in perceiving.[13] To use an updated terminology, we could say that according to Husserl there can be no perception without *awareness of the acting body.* Following the perspective I tried to sketch in the present paper, it could be added that the *awareness* of our acting body cannot be detached from the mechanisms presiding over *action control* (see also Gallese, 2000a, b). By accepting these premises, the bridge to be crossed to get from *acting* to *thinking* narrows considerably.

According to Husserl, what makes the behaviour of other agents intelligible is the fact that their body is experienced not as material object (Körper), but as something alive (Leib), something analogous to our own experienced acting body (for a discussion of the concept of *bodily presence*, or Leibhaftigkeit, see Pacherie, 1999). Empathy is deeply grounded in the experience of our lived-body, and it is this experience that enables us to directly recognize others not as bodies endowed with a mind but as *persons* like us.[14] Persons are rational individuals. What we now discover is how a rationality assumption can be grounded in bodily experience.

This relationship between agency and intersubjectivity becomes even more evident in the works of Edith Stein and Merleau-Ponty. In her book *On the Problem of Empathy* (1912/1964, English translation), Edith Stein clarifies that the concept of empathy is not confined to a simple grasp of the other's feelings or emotions. There is a more basic — and I would add aboriginal — connotation of empathy: the other is experienced as another being like oneself through an appreciation of *similarity.* An important component of this similarity resides in the common experience of action. As Edith Stein points out, if the size of my hand were given at a fixed scale, as something predetermined, it would become very hard to empathize with any other types of hand not matching these predetermined physical specifications. However, we can perfectly recognize children's hands and monkeys' hands as such despite their different visual appearance. It is indisputable that we recognize hands because, basically, they all look the same, they all have five fingers, a thumb, etc. However, we can recognize hands as such even when all these visual details are not available, even despite

[13] The relation between Husserl's thought on intersubjectivity and neuroscience has been extensively explored by Jean-Luc Petit (1996; 1997; 1999). See also Sheets-Johnstone (1999).

[14] A similar account can be found in Metzinger (1993; 2000) when he posits that the seen body of the other is modelled as 'Leib' through the phenomenal self-model.

shifts of our point of view, and even when no visual shape specifications are provided as in the case of the luminous dot-display experiments mentioned above. This seems to suggest that our 'grasping' of the meaning of the world doesn't *exclusively* rely on its visual representation, but is strongly influenced by action-related sensorimotor processes.

Merleau-Ponty in the *Phenomenology of Perception* (1962) writes:

> The sense of the gestures is not given, but understood, that is, recaptured by an act on the spectator's part. The whole difficulty is to conceive this act clearly without confusing it with a cognitive operation. The communication or comprehension of gestures come about through the reciprocity of my intentions and the gestures of others, of my gestures and intentions discernible in the conduct of other people. It is as if the other person's intention inhabited my body and mine his.

Self and other relate to each other, because they both represent opposite extensions of the same correlative and reversible system *self/other.* The observer and the observed are part of a dynamic system governed by reversibility rules. Merleau-Ponty argues against the Cartesian equivalence between seeing and thinking, emphasizing the 'narcissistic' character of vision.

This line of thought, however, is not a prerogative of 'continental philosophy', but permeates also the tradition of American Pragmatism. Herbert Mead (1912) writes:

> Any gesture by which the individual can himself be affected as others are affected, and which therefore tends to call out in him a response as it would call out in another, will serve as a mechanism for the construction of a self.

One important aspect of the *self* is the result of the individual's mirroring in the social organization of the outer world. According to Mead, the only way to *objectify* us is to assume the other's perspective, like looking at our reflection in a mirror. Through the medium of intersubjective communication the consequences produced by our actions in the observed behaviour of others contribute to build our personal identity (see Mead, 1934).

VI: The *Shared Manifold* Hypothesis

The main thesis of this paper so far has been that agency plays an important role in establishing meaningful bonds among individuals, by enabling them with a direct, automatic, non-predicative, and non-inferential simulation mechanism, by means of which the observer can recognize and understand the behaviour of others. I submit that the neural matching mechanism constituted by mirror neurons — or by equivalent neurons in humans — described in the present paper, is crucial to establish an empathic link between different individuals.

However, action is certainly not the only medium through which we can empathize with others. When we enter in relation with others there is a multiplicity of states that we share with them. We share emotions, our body schema,[15] our being subject to pain as well as to other somatic sensations. At this point we need a conceptual tool to capture the richness of the experiences we share with others.

I will introduce this conceptual tool as the *shared manifold* of intersubjectivity. I posit that it is by means of this shared manifold that we recognize other human beings

[15] See Berlucchi and Aglioti (1997) for a discussion of the neural bases of body awareness.

as similar to us. It is just because of this shared manifold that intersubjective communication and mind-reading become possible.

The shared manifold can be operationalized at three different levels: A phenomenological level; a functional level; and a subpersonal level.

- The *phenomenological level* is the one responsible for the sense of similarity, of being individuals within a larger social community of persons like us, that we experience anytime we confront ourselves with other human beings. It could be defined also as the *empathic* level, provided that empathy is characterized in the 'enlarged' way I was advocating before. Actions, emotions and sensations experienced by others become meaningful to us because we can *share* them with them.
- The *functional level* can be characterized in terms of simulation routines, *as if* processes enabling models of others to be created.
- The *subpersonal level* is instantiated as the result of the activity of a series of mirror matching neural circuits. A dual mode of operation, an *expressive* mode and a *receptive* mode characterizes these circuits. The activity of these neural circuits is, in turn, tightly coupled with multi-level changes within body-states (see below).

So far I have provided evidence supporting the notion that the representation and understanding of the observed behaviour of others is made possible through a simulation mechanism that matches action observation and execution onto the same neural substrate. What about the other elements that compose the *phenomenological level* of the aforementioned *shared manifold*? What about sensations, pains, and emotions? My proposal is that also sensations, pains and emotions displayed by others can be empathized, and therefore understood, through a mirror matching mechanism.

Let us now see how this hypothesis can be supported by empirical data (this is what people expect from neurophysiologists . . .). Preliminary evidence suggests that in humans a 'mirror phenomenon' occurs in pain-related neurons. Hutchison *et al.* (1999) studied pain-related neurons in the human cingulate cortex. Cingulotomy procedures for the treatment of psychiatric disease provided an opportunity to examine prior to excision whether neurons in the anterior cingulate cortex of locally anesthetized awake humans respond to painful stimuli. It was noticed that a neuron that responded to noxious mechanical stimulation applied to the patient's hand also responded when the patient watched pinpricks being applied to the examiner's fingers. Both applied and observed painful stimuli elicited the same response in the same neuron. It is not difficult to characterize the behaviour of this human nervous cell during observation in the functional terms of *simulation, simulation of pain experience.*

A recent study published by Calder *et al.* (2000) shows that a Huntington patient who suffered damage to subcortical structures such as the insula and the putamen, is selectively impaired in detecting disgust in many different modalities, such as facial signals, non-verbal emotional sounds, and emotional prosody. The same patient is also selectively impaired in subjectively experiencing disgust and therefore in reacting appropriately to it. This clinical case, with all cautions required when single cases are involved, seems to suggest that once the subject has lost the capacity to *experience* and *express* a given emotion, the same emotion cannot be easily *represented* and *detected* in others.

As recently underlined by Jarvilehto (forthcoming), emotions are not an unnecessary addition to cognitive processes, but they constitute one of the earliest ways to acquire knowledge about the situation of the living organism, and therefore to reorganize it in the light of its relations with others.

This points to a strong interaction between emotion and action. We dislike things that we seldom touch, look at or smell. We do not 'translate' these things into motor schemas suitable to interact with them, which are likely 'tagged' with positive emotions, but rather into aversive motor schemas, likely 'tagged' with negative emotional connotations. The coordinated activity of sensorimotor and affective neural systems results in the simplification and automatization of the behavioural responses that living organisms are supposed to produce in order to survive.

I posit that the strict coupling between affect and sensorimotor integration can be one of the most powerful drive leading the developing individual to the achievement of progressively more 'distal' and abstract goals.

VII: Conclusions

To summarize, there is preliminary evidence that the same neural structures that are active during sensations and emotions are active also when the same sensations and emotions are to be detected in others. It appears therefore that a whole range of different 'mirror matching mechanisms' may be present in our brain. This subpersonal architecture of simulation, that we originally discovered and described in the domain of actions (diPellegrino *et al.*, 1992; Gallese *et al.*, 1996a; Rizzolatti *et al.*, 1996a), is likely a *basic* organizational feature of our brain. Damasio (1999) has clearly pointed out that one of the mechanisms enabling feelings of emotion to emerge, is the activation of neural '*as if* body loops'. These simulation mechanisms, by-passing the body proper through the *internal* activation of sensory body maps, create a representation of emotion-driven body-related changes. The activation of these '*as if* body loops' can likely be not only internally driven, but also triggered by the observation of other individuals (for a discussion of the relation between empathy and Simulation Theory, see Goldman, 1993b).

The discovery of mirror neurons in the monkey premotor cortex has unveiled a neural matching mechanism that, in the light of more recent findings, appears to be present also in a variety of non motor-related human brain structures. Different *simulation routines* are applied in different domains, being sustained by a dual-mode of operation (*active* and *passive*, *expressive* and *receptive*) of given brain structures.

How can we reconcile this *embodied* account of representation with reason and thought? As already pointed out by Hume (1978, ed. Selby-Bigge), inductive reasoning is large part of our explanatory approach to the world in which we live. By inductive reasoning, we can apply the results of our previous experiences to unprecedented events and novel states of affairs. Induction, although not necessarily inferentially sound, determines our pervasive tendency to detect cause-effect relations. I hope that at the end of my paper the reader will be able to appreciate how the inductive aspects or reasoning — considered by many theory-theorists to be at the basis of the human understanding of other minds — could be underpinned by the different embodied simulation routines unveiled by neuroscientific investigation, here briefly summarized.

Complex traits, such as mind-reading abilities, are the result of a long evolutionary process. It is reasonable to hypothesize that this evolutionary process proceeded along a line of continuity (see Gallese and Goldman, 1998; Gallese *et al.*, 2001b). Andrew Whiten (1996) has written:

> mind-reading is not telepathy. So, the recognition of another's state of mind must rest on observation of certain components within the complex of others' behaviour patterns together with their environmental context: that's all we can see. . . . This means that the contrast of mind-reading with behaviour-reading is not so straightforward as it may first appear.

Much of what we ascribe to the mind of others when witnessing their actions depends on the 'resonance mechanisms' that their actions trigger in us. The detection of intentions that we ascribe to observed agents and that we assume to underpin their behaviour is constrained by the necessity for an intersubjective link to be established. The shared manifold I described above determines and constrains this intersubjective link. It could be provocatively added that — quite opposite to what many theory-theorists maintain — explicit theorizing is the only strategy available when the embodied resonance mechanisms of the shared manifold are deficient, as likely occurring in the case of autism.

My conclusion is that the more we'll know about how our brain-body system works, the less remote the nature of thought and reasoning will appear from it.

Acknowledgment

The author wishes to thank Giacomo Rizzolatti, Thomas Metzinger, and Christian Keysers for their most valuable comments on an earlier version of this article. This work was supported by grants from MURST and HFSP to V.G.

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